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THE TRANSFORMATION OF HUMAN METABOLIC PRODUCTS AND PRODUCTS OF A BIOLOGICAL COMPLEX DURING THE RECIRCULATION OF SUBSTANCES IN SMALL, CLOSED SPACES

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ABSTRACT

The authors discuss the problems involved in creating life-support systems on the basis of recirculation of substances in closed spaces. The three stages identified are: a) completely closed cycle, including regeneration of water, purification of the atmosphere, and providing man with food; b) partially closed cycle, including regeneration of water and the atmosphere and obtaining food products of plant origin with the existence of an unreplenished supply of food products of animal origin; c) open life-support system leased on supplies of food but including regeneration of water and atmosphere. Mineralization of solid and dehydrated waste products is discussed.

Creating a system for supporting human life on the basis of even partial recirculation of substances is possible if repeated use is made of the chemical elements and simplest compounds entering into the composition of the food products required by man. For this purpose human solid and liquid excrement, scraps from the kitchen, and the space hothouse, and bio-regenerators of the atmosphere must go through a process of mineralization. As a result of mineralization and additional physico-chemical correction the needed chemical elements can be returned through recirculation of substances in forms which are suitable for use by autotrophic and heterotrophic organisms. /1*

In principle the link of mineralization can be based on physico-chemical and biological methods as well as on an integrated combination of them. The impossibility at the present time of giving a definite, comparative evaluation to mineralization and selecting a method for performing it dictates the need to use several criteria, that is, the completeness of mineralization and the extent of change of the chemical and aggregate composition of products and the coefficient of return and also the weight and the dimensions of

*Numbers given in the margin indicate the pagination in the original foreign text.

the equipment used and the power needed to operate it. The composition and properties of the initial products which are subjected to mineralization determine in large measure the possibility and need to use a particular method.

The methods of thermal and thermocatalytic oxidation can best be used /2 to mineralize the solid and deyhdrated waste products of man and a biological complex.

The thermal method using temperatures ranging from 700 to 800°C makes it possible to mineralize practically all waste products of a biological complex and human excrement. This method is technologically simple although the consumption of energy and oxygen is still high. The end products of thermal mineralization are ash and gaseous products containing carbon dioxide, sulfurous oxides, etc. The mineral content of the ash is relatively constant over a wide range of combustion regimes but its physico-chemical properties vary (solubility, specific gravity, etc.). One shortcoming of this method is the possibility of formation of molecular nitrogen at certain regimes leading as a consequence to disruption of the nitrogen balance in the system. This requires additional consumption of power to bind the nitrogen. However, the need to burn completely those products which are not susceptible to other methods of mineralization dictates the inclusion of the thermal method in one form or another in life-support systems. The use of this method is especially important in partially closed systems when the purpose of treating the waste products is their elimination or prolonged storage.

The thermocatalytic method (oxidizing-catalytic) may prove to be one of the most promising. The main advantage of this method is the relatively small amount of energy required and the possibility of getting a solution of mineral acids which are needed for dissolving the ash and correcting the culture media. Initial temperatures on the order of 200°C are needed to carry out the process of thermocatalytic oxidation. The process of mineralization takes place under less intense conditions than is the case with the thermal method, forming ash which in physico-chemical properties is more convenient for further processing. The difficulty of conducting the process under heterogeneous conditions and the complexity of selecting long-acting, stable catalysts are shortcomings of the thermocatalytic method. This method can best be combined with the thermal for use in partially closed systems when the main purpose of processing waste products is to obtain solutions of mineral ash for correcting the culture media.

For the purpose of mineralizing human liquid excretion, diluted urine-fecal matter, and condensate after drying and squeezing out the unused parts of plants, the method of oxidation in the liquid phase--"wet burning" (by using increased concentrations of oxygen or the introduction of other oxidizers)--at increased temperatures and presures may be used.

The method of "wet burning" is extremely complex and inadequately studied although in principle it has many advantages, such as the possibility of /3 obtaining a solution of mineral salts directly. The presence in waste products subjected to mineralization of a large amount of organic substances often not of constant composition complicates considerably directing the

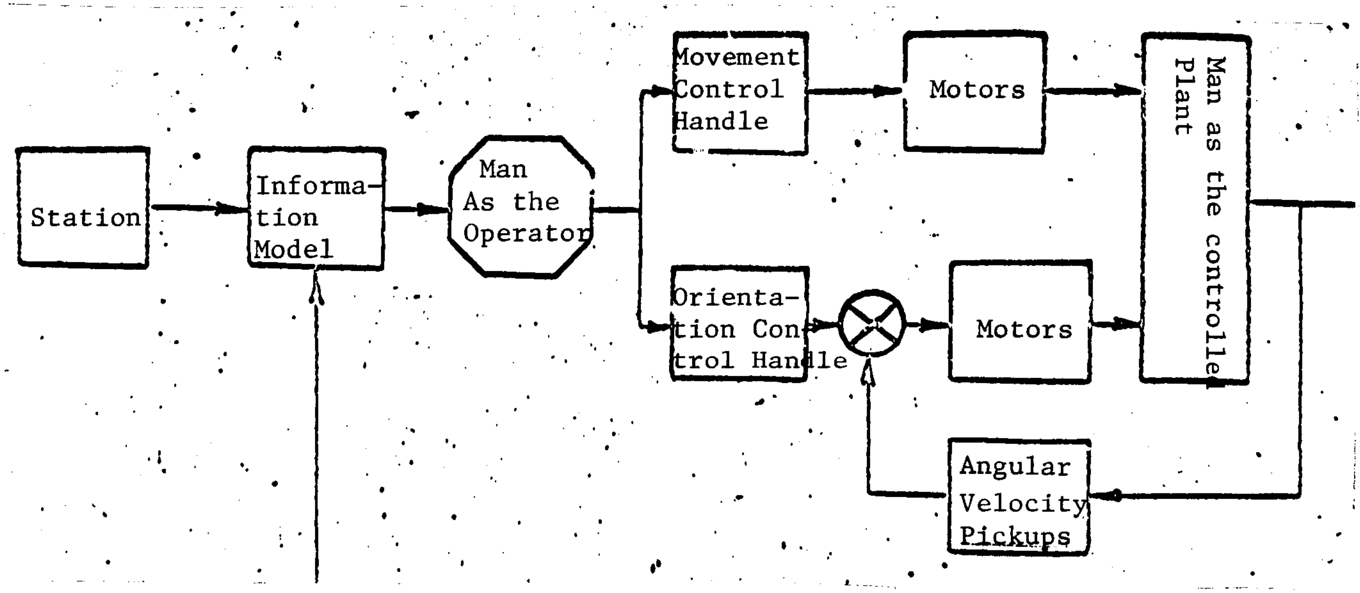

Fig. 3. Block diagram of manual control system for extravehicular movement by a cosmonaut.

process of mineralization in such a way as to obtain a solution of a particular composition.

Experimental investigation on mineralizing by the "wet burning" method showed that the extent of mineralization of urine-fecal and fecal matter reaches 90%. However, the remaining unidentified organic substances are exceedingly toxic for plants and they must be further processed or removed.

It is possible that when human waste products are oxidized using this method not only decomposition of initial organic substances takes place but also the synthesis of new ones. In the vapor-gas phase after mineralization traces of hydrogen, saturated and unsaturated hydrocarbons, and ammonia are detected. The high pressure (up to 150 atm) and the high temperature of the process (250—275°) must also be listed under the technological difficulties of this method.

The method of "wet burning" can be used for thermohydrolysis of urea and for obtaining ammonia and nitric acid. On the whole the method, despite several fundamental positive aspects, has not yet been mastered and as yet it is difficult to evaluate its place in the life-support system of spaceship.

Biological mineralization is another possible method for use in life-support systems. In developing biological mineralization of human metabolic products, the theoretical concepts on the transformation of substances and energy in nature which came about during the course of evolution are applied.

At the beginning of the investigation an aerobic process was selected as a result of which mineralized media could be obtained (in gas or liquid form) to satisfy the needs of autotrophic and hetrotropic links. Gradual intensification of the process of biological mineralization was brought about by a certain change in the technology of the process:

the total number of microbe-mineralizers was increased in the mode by using a regenerator of active ooze;

the use of oxygen was increased by longer contact of the mineralizing medium with the air without increasing the duration of aeration;

higher temperatures were used in cultivating an active ooze.

It was found that in experiments of long duration a concentrated solution (1:30) of human urine-fecal excretion mineralizes in a period of 4 hours of aeration with respect to substances containing carbon by 85% and substances containing nitrogen are transformed by 95% into nitrate forms. This makes it possible to use the mineralized solution directly in preparing culture media for autotrophs.

In mineralizaing solid and liquid human excretion and plant waste products part of the substances goes through a vapor-gas stage. Its composition and quantity fluctuate considerably and depend on the composition of initial /4 mineralized products, the methods used in mineralizing, and the modes and conditions under which the process is conducted. This accounts in large measure for the complexity of the problem in returning to recirculation substances which are in a vapor-gas stage.

Another basic process used to process gaseous organic substances is mineralizing them with subsequent separation and recovery. In principle, separation and recovery of substances from the vapor-gas stage are possible via sorption and physico-chemical separation. As a result of these processes many compounds are transformed into a solid or liquid state which simplifies returning them to recirculation of substances in the form of culture media.

The catalytic method is one of the most promising methods of mineralizing gaseous substances. It makes it possible without identification of complex organic compounds to obtain higher oxides of nitrogen and sulfur, carbon dioxide, and water.

Research into the mineralization of solid and liquid human excretion has demonstrated that in processing the amount of excretion produced in a day, depending on the method used, there is transformed to the vapor-gas phase up to: 3.0—4.0 g of molecular nitrogen, 0.5 g of hydrogen, 3.0 g of carbon monoxide, 7.0 g of ammonia, and 5.0 g of saturated and unsaturated hydrocarbons. In this process up to 122 g of carbon dioxide is formed and up to 60 g of oxygen is consumed. Mineralization and purification of vapor-gas mixtures must be sufficiently complete in order that the indicated mixture going to the autotrophic link contain only nitrogen, oxygen, and carbon dioxide.

A comparison of several systems for mineralization of vapor-gas mixtures showed that the following sequence of steps is highly advisable. At first nitrogen and sulfur compounds are separated in the form of corresponding acids from the total mixture of gaseous products. Further, during the catalytic oxidation carbon monoxide, hydrogen, and hydrocarbons are transformed into carbon dioxide and water.

Performing the mineralization of solid and liquid human excretion and plant waste products is connected in the closest possible way with the processes of regeneration, conditioning, and storing the water extracted from products which contain moisture, that is, a condensate of atmospheric moisture and transpired water. Although questions of regenerating water constitute one of the aspects of the problem of recirculation of substances in small, closed spaces, at the present time they are being answered with respect to definite, closed life-support systems and therefore the degree of their experimental and technological treatment is much higher.

It is highly advisable to use a water supply link based on regeneration of water from metabolic products containing moisture on flights lasting /5
15—20 days . Calculations have shown that on a flight lasting one day or one week the required water supply remains relatively small and for a crew of three it comes to 16.5 and 115.5 kg, respectively. But for a flight lasting 30 days the amount of water needed reaches 495 kg. The weight of a unit to regenerate water may fluctuate only within the limits of 20—50 kg regardless

of the duration of flight. This is one of the factors requiring that extensive investigation be made into developing a link for regenerating water from human metabolic products containing moisture and a biological complex.

The most realistic average daily need for water of one man is 4 liters. Included in this amount is 1200 ml of drinking water, 1000 ml for the preparation of food (including natural juices), and 1800 ml for sanitary-hygienic needs (during flights of average duration). Understandably, the proportion of water which goes into food or is intended for drinking will vary depending on the food ration. If the food consists of dehydrated products the amount of water set aside for drinking purposes must be increased correspondingly.

The sources from which the supply of water can be increased are the condensate from atmospheric moisture, urine, water used for washing, and in case of the presence on board of plants, transpired water from the higher plants and fugaceous parts of unicellular algae. The amount of water obtained in this way will be sufficient to provide a crew with water for drinking purposes, the preparation of food, sanitary-hygienic needs, and also for preparing mineral culture media.

Methods have been worked out to regenerate water from human metabolic products. The most promising of them are: oxidizing-catalytic, vacuum distillation, and lyophilization (molecular drying). The last method is of value in the event a vacuum is used in the low temperatures of outer space. Investigation into purifying water with the help of several sorbents, including an ion exchanger, with a preliminary oxidiation of organic substances and also with the use of semipermeable membranes have given good results. It is also possible to use electrochemical methods, ozoniation, ultrasound, and irradiation to regenerate water from waste products containing water.

The table presents some information on the sanitary-chemical properties of water regenerated using the methods of lyophilization, vacuum distillation, and catalytic oxidation. It follows from these data that water in many cases requires additional sorbent purification. In tests using humans and animals chemical, bacteriological, toxicological, and clinco-physiological evaluations of regenerated water were performed.

In solving the problems involved in creating life-support systems on the basis of recirculation of substances in closed spaces it is possible to identify several stages in a step-by-step review of the problem:

completely closed cycle including regeneration of water, purification of the atmosphere to necessary conditions, and, what is most important, providing man with food products (optimal task);

partially closed cycle including regeneration of water and the atmosphere and obtaining food products of plant origin with the existence of unreplenishable supply of food products of animal origin (this problem must be solved in the very near future);

Table /6

Chemical Composition of Water Regenerated from Urine Using Various Physicochemical Methods

Chemical composition of water	Quantity of substance after regeneration of urine using the method of:			Maximum allowable value of indicator
	Catalysis	Lyophilization	Vacuum distillation	
Organic nitrogen	0	6	2	0
Nitrogen of ammonia	0.2	2.8	9	1
Nitrogen of nitrites	0.01	0.01	0.1	0.01
Nitrogen of nitrates	0.12	0.1	0.01	2– 40
Oxidizability of O_2 in mg/l	1.5	2.9	9.1	2– 6
Chlorides	2.0–3.0	7.1	20.3	200
Sulfates	trace	tr	0	20–80
Phosphates	0.01	0.02	0	0.1
Calcium	trace	tr	0	-
Magnesium	0	tr	0	-
Overall hardness in mg equiv/l	0	0	-	7
Transparency in cm	25.	30	25	30
Chromaticity in degrees	10	—	10	20
Odor in points	0	0	2	2
rN of medium	6–7	6	6	6; 5–8
Urea	0	0	0	—
Uric acid	0	0	0	—
Creatine	0	0	0	—

open life-support system based on supplies of food but including regeneration of water and atmosphere (the problems of today).

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The link of mineralization and physicochemical correction in the overall life-support system, in our opinion, is a basic stage where the main flow of human metabolic products and the biological complex converges and closes. It is in just this link that the new cycle of return of biogenic elements in the form of culture media and carbon dioxide return to the autotrophic link.

In the absence of heterotrophs, the life-support system will accumulate a certain amount of unused substances, the total quantity of which should not exceed the food supplies being consumed.

In the absence of heterotrophs in the life-support system the problem of mineralization is reduced to processing and preserving waste products or eliminating them.

The design of the link for mineralization, the functional interlinkage, and the interdependence of methods and units must be determined by the need for maximum output of elements and the simplest compounds for providing mineral nutrition for autotrophs with a minimum of power consumed, weight, dimensions, etc., and with a high degree of reliability and controllability.

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